TECHNICAL NOTE

D-1282

SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES

By Morgan P. Hanson and Hadley T. Richards

Lewis Research Center
Cleveland, Ohio

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON May 1962

1Y

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

TECHNICAL NOTE D-1282

E-1447

SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES

By Morgan P. Hanson and Hadley T. Richards

SUMMARY

The purpose of the present investigation was to summarize data in the literature and combine them with data obtained at the Lewis Research Center on the mechanical properties of the titanium alloy Ti-6Al-4V at temperatures of 75°, -320°, and -423° F. Results are reported for sheet material that ranged in thickness from 0.030 to 0.090 inch. Most of the material tested was in the annealed condition. Limited data are presented for material in the solution-treated condition and for welded material. Smooth tensile and yield strengths, notch tensile strength, and percent elongation are presented for all test conditions. Edge-notched tensile specimens had stress-concentration factors K_t of 3.0, 7.2, and 21.0

The smooth tensile and yield strengths nearly doubled from 75° to -423° F. Generally, notch tensile strengths increased when the test environment temperature was reduced from 75° to -320° F but decreased sharply at -423° F. Large variations in notch strength resulted from the different values of K_t and the different heats and thicknesses. The elongation was generally reduced with lowered temperature; however, the elongation did not indicate the severity of embrittlement that was evidenced by the low notch strengths at the low temperatures. Variations in interstitial content did not appear to account for the large variations in notch strength. The alloy does not exhibit directionality, since all the mechanical properties were essentially the same in both the longitudinal and transverse directions. The alloy was 100 percent weld efficient at all test temperatures; however, the weld metal was more notch sensitive than the parent metal, especially at -320° F.

INTRODUCTION

Titanium alloys are attractive materials for use in space vehicles because these alloys generally have high ratios of strength to density. A possible major application for titanium alloys in space vehicles could be in propellant tanks. For vehicles in which liquid oxygen and liquid hydrogen are used as propellants, the tanks would be subjected to temperatures ranging from about -297° F (boiling point of liquid oxygen) to -423° F (boiling point of liquid hydrogen). At these low temperatures, many metals have high ultimate strength, but the ductility and fracture toughness may be so low as to render the material impractical for use in tanks for cryogenic fluids. It is desirable, therefore, that the designer have available as much information on the mechanical properties of a given material as practicable so that reliable cryogenic tank structures can be fabricated.

Several investigators have reported the mechanical properties of Ti-6Al-4V alloy over extended temperature ranges as low as -423° F (see refs. 1 to 4); however, the total amount of information available is relatively small. It is the purpose of the present investigation to provide additional information and to comment upon the significance of the present results in conjunction with those that have been published.

The data for the present investigation were obtained from Ti-6Al-4V sheet of two different heats in the annealed condition. One heat was also tested in the solution-treated condition. The sheet thicknesses were approximately 0.030 and 0.035 inch. The smooth and sharp-notch tensile strengths of the alloy were obtained at room temperature, -320° and -423° F. Some smooth and sharp-notch properties of welded Ti-6Al-4V sheet material also were obtained. The data from the present investigation are compared with those obtained previously (refs. 2 to 4).

MATERIAL AND TEST SPECIMENS

Material

The Ti-6Al-4V investigated was commercial sheet material. The heat numbers and chemical compositions of the materials of the present and previous investigations are given in table I. The 0.030- and 0.035-inch-thick sheets of the present investigation were of two different heats and were received as annealed. One heat was tested in the annealed condition only, while the other heat was tested in the annealed and solution-treated conditions. Both heats were annealed at 1350° F for 8 hours. The solution treatment was done at 1670° F for 1 hour followed by a rapid quench.

E-1447

Test Specimens

Sketches of the smooth and sharp-notch tensile specimens used in the present investigation of 0.030- and 0.035-inch sheet are shown in figure 1. Details regarding selection of this particular specimen design and the techniques used in preparation of the specimens are discussed in reference 5. The specimens were machine contoured in the as-heat-treated condition with the machining limited to the edges.

The weld specimens were made from coupons cut from panels welded by the supplier after heat treatment. The location of the weld in the test specimen is also shown in figure 1. Weld specimens were prepared from material in both the annealed and solution-treated conditions. The welds were fusion butt welded using an inert-gas-shielded arc with a noncon-sumable electrode. No filler material was used in the weld. Both the weld face and backup were inert-gas shielded. Radiographic inspection detected no defects in the welded joints. In the tests of welded sheet, the bead was not removed, since the thickness of the weld was essentially the same as that of the parent metal.

APPARATUS AND PROCEDURE

Tensile Testing Equipment

Tests at 75°, -320°, and -423° F were made with a universal testing machine. The cryogenic test temperatures were established by immersing the test specimens in liquid nitrogen (-320° F) or liquid hydrogen (-423° F) during load application. Cryostats were used to reduce boiloff of the liquid nitrogen or hydrogen to reasonable minimums during the test period. Details of the cryostats are given in reference 6.

Procedure

The smooth tensile strength, yield strength (0.2 percent offset), percent elongation in 2 inches, and notch tensile strength were determined at 75°, -320°, and -423° F. Tests at room temperature involved no special techniques.

For the tests at cryogenic temperatures, the first step was to mount the specimen in a suitable cryostat where it could be submerged in a cryogenic liquid. For the tests at liquid-nitrogen temperature, the specimen was submerged by pouring liquid nitrogen into an open-top cryostat until the liquid level was above the upper grip. The boiloff rate of the liquid nitrogen in this cryostat was low enough so that once the specimen was submerged and cooled to the temperature of the liquid nitrogen no further addition of liquid nitrogen was necessary for the duration of each test.

For the tests in which liquid hydrogen was required, the specimen was installed in a gas-tight cryostat. As a safety measure, the air in the hydrogen supply lines and in the test chamber was first purged with gaseous helium. Liquid hydrogen was then introduced until the specimen temperature had reached that of the liquid hydrogen. A small flow of liquid hydrogen was required to maintain the proper liquid level throughout the test period.

The ultimate tensile and yield strengths were based on the specimen cross-sectional area calculated from measured thickness and width before tension tests. The sharp-notch strengths were based on the area resulting from the product of the unwelded sheet thickness and the width between roots of the notches. The strain rate was less than 0.005 inch per inch per minute.

The stress-concentration factor K_t used throughout this report was calculated from the following equation presented in reference 7:

$$K_t = 1 + \sqrt{\frac{\left(K_{t,e} - 1\right)^2 \left(K_{t,h} - 1\right)^2}{\left(K_{t,e} - 1\right)^2 + \left(K_{t,h} - 1\right)^2}}$$

where the stress-concentration factors for elliptical and hyperbolic notches are, respectively,

$$K_{t,e} = 1 + 2\sqrt{\frac{t}{r}}$$

$$K_{t,h} = \frac{2\left(\frac{a}{r} + 1\right)\sqrt{\frac{a}{r}}}{\left(\frac{a}{r} + 1\right)\tan^{-1}\sqrt{\frac{a}{r}} + \sqrt{\frac{a}{r}}}$$

and

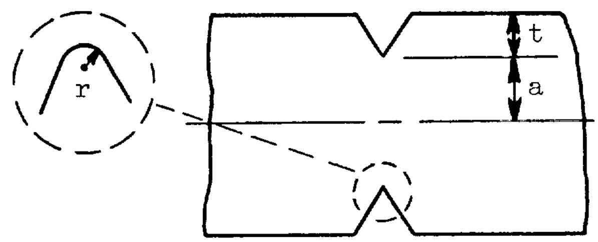
t depth of edge notch

r notch radius

a half minimum width

This equation is used to calculate the stress-concentration factors of notches in finite members under tension and is applicable to edge notches.

The locations of t, a, and r are shown in the following sketch:



E-1447

RESULTS AND DISCUSSION

The mechanical properties of two heats of the titanium alloy Ti-6Al-4V were determined in the present investigation. The test data and associated averages are presented in table II. Properties are given for both heats of parent metal in the annealed condition and for one of these heats that was subsequently solution-treated. Values are also given for specimens containing butt welds, which had been made in the annealed and solution-treated sheet.

Influence of Temperature on Mechanical Properties

The tensile properties of the Ti-6Al-4V alloy recently tested at the NASA are shown in figure 2. This figure is a plot of the average data from table II showing the effect of temperature. The curves are dashed between room temperature and -320° F to indicate interpolation for the large temperature interval. Only longitudinal data were available for figure 2(a); longitudinal and transverse values are plotted in figures 2(b) and (c).

It was apparent that the tensile and yield strengths of the alloy, under the individual material conditions tested, approximately doubled in value as the test temperature was lowered from 75° to -423° F. For both heats in the annealed condition (figs. 2(a) and (b)), the yield strength was very near the tensile strength. Subsequent solution treatment of the one heat (fig. 2(c)) showed a slight increase in tensile strength; however, the yield strength remained about the same as in the annealed condition.

The sharp-notch tensile strengths of the two heats in figure 2 show different trends than do the smooth tensile and yield strengths. It is believed that these trends in notch strength can be more easily compared by referring to figure 3(a), where the ratio of notch to smooth tensile strength is plotted as a function of temperature. In figure 3(a) it is shown that the material of both heats and both heat treatments is notch sensitive at liquid-hydrogen temperature, since here the ratios of notch to smooth tensile strengths range from 0.41 to 0.59. Between room temperature and -320° F, however, annealed heat M-7197 is essentially notch insensitive, as shown by notch-to-tensile ratios of 1.20 at room temperature and 0.97 at -320° F. For heat M-7373, the material is notch insensitive at room temperature, but at -320° the tensile ratio is 0.76. It can be observed that the solution treatment of heat M-7197 significantly increased the notch sensitivity; however, at 75° F the alloy was notch insensitive in both the annealed and solution-treated conditions. The results of figure 3(a) also indicate that there can be large differences in notch sensitivity between materials of different heats that undergo the same annealing treatment. In this particular investigation there were relatively small differences in material thickness (0.030 and 0.035 in.), and it is believed that such a thickness variation would not cause large variations in the notch sensitivity. The large difference in notch sensitivity between different heats of the same material is not clearly understood; however, the notch strength ratio appears to be an inverse function of the tensile strength for the three test temperatures, as is shown in figure 3(b). This relation is in better agreement as the notch strength ratio is lowered. With this alloy it is apparent that, within the temperature limits used, notch sensitivity can be avoided but with a sacrifice in tensile strength. The sensitivity to notches may be the result of other factors that are discussed later in this report.

E-1447

The alloy exhibited shear fractures at all test temperatures for all notched specimens. The fracture appearance does not indicate the embrittlement that would be expected in view of the low sharp-notch strengths.

Figure 2 also shows the average elongation of the materials tested as a function of the test temperature. The range of the individual data points at a given test temperature is shown by the brackets. It is apparent that the variation is generally more pronounced at the low temperatures. This variation can be attributed, in part, to the plastic flow behavior observed in the fractured specimens. Some specimens were noted to have yielded only in a limited area near the fracture. This has been observed previously in stainless steels with high amounts of cold reduction (ref. 6). Of the two annealed heats (figs. 2(a) and (b)), the average elongation behavior is similar from 75° to -320° F. At -423° F, however, the elongation of heat M-7197 was reduced markedly, while the elongation of heat M-7373 actually increased from that at -320° F. The low elongation in heat M-7197 at -423° F can be attributed, in part, to the proximity of the yield and tensile strengths (3000 psi), whereas in heat M-7373 the difference between yield and tensile strengths was greater

(11,000 psi). The elongation of the solution-treated heat M-7197 increased at -320° F over that at room temperature; however, at -423° F the elongation was about the same as in the annealed condition (fig. 2(c)).

It is interesting to note that the elongations in these tests do not indicate the severity of embrittlement, as evidenced by the low notch strengths at the low temperatures. Actually, the more notch sensitive material had the higher elongation at -423° F.

E-1447

The M-7197 alloy does not appear to be directional, as indicated by the close agreement of the longitudinal and transverse properties of heat M-7197. There was no marked difference in any of the properties shown in figure 2 with respect to rolling direction. Data for M-7373 were limited to the longitudinal direction.

Weld Properties

Figure 4 summarizes the results that were obtained with welded specimens in both the smooth and notched configurations. There was no heat treatment after welding except for one data point noted in figure 4(b). The data are plotted as the ratio of the weld strength to the parent metal strength for the temperature range 75° to -423° F. The strength ratios for solution-treated heat M-7197 and annealed heat M-7373 are shown. The smooth tensile properties of the welded specimens were essentially the same as those of the parent material (100 percent weld efficient) for the entire temperature range (fig. 4(a)). For the smooth welded specimens, the fractures generally occurred outside the weld and the associated heat-affected zone for all test temperatures; hence, the weld metal was stronger than the parent metal. An exception to this trend, however, was the annealed specimens of M-7373 that were tested at -423° F. Three out of four of these specimens fractured within the weld.

The notch strength of welded specimens was generally lower than that of notched specimens of the parent metal. This is apparent in figure 4(b), where the strength ratios of the welded notch specimens of both annealed and solution-treated material were generally less than 1.0. For the annealed material, the tensile-strength ratios at 75° and -423° F were 0.91 and 0.94, respectively. At -320° F, however, the tensile-strength ratio dropped to a value of 0.64. Stress-relieving the weld at 1300° F for 1 hour did not improve the notch strength at -320° F, as shown in figure 4(b).

Comparison of Properties

To provide useful information to designers, the data obtained in the present investigation are compared with the data previously published in references 2 to 4. It should be pointed out that the comparison includes materials from different heats and in some cases materials of different thicknesses. Data from notch specimens of different geometry are also considered. Direct comparisons of the notch data from the various sources may therefore not be valid. The smooth tensile data, however, can be compared directly to show variations due to the different heats. A general discussion of the overall data trends may be of some use.

Figure 5 shows the longitudinal tensile properties of annealed Ti-6Al-4V sheet as functions of test temperature for previously published data. NASA data from figure 2 are included for comparison. The data represent properties of eight different heats with nominal material thicknesses varying from 0.030 to 0.090 inch. All heats exhibit similar trends in the smooth tensile and yield properties as test temperature varies (figs. 5(a) and (b)). The curves enveloping the extremes of the data are probably representative properties of the alloy, since the data shown are quite evenly distributed at a given test temperature. The fact that the relative position of the smooth tensile and yield properties is the same from 75° to -423° F indicates there were no unusual temperature effects.

The considerable variation in the notch tensile data obtained in various investigations is shown in figure 5(c). Part of the variation is due to the different stress-concentration factors K_t that resulted from the different notch geometry used for the test specimens employed by the various investigators. Values of K_t of 3.0, 7.2, and 21.0 are represented. Only one set of data was available for a K_t of 3.0. As would be expected, the highest notch strengths are associated with this lowest K_t value. For the higher values of K_t, three and four sets of data were available, and it is apparent that large variations in the notch strength occur at a given K_t value for the various data sources. Notch strength is obviously affected by the different heats. In all probability, this obscures the influence of thickness since there does not seem to be any consistent trend due to thickness when all temperatures are considered. Generally, for a given value of K_t, the notch strength increases as the temperature decreases from 75° to -320° F. From -320° to -423° F the notch strength decreases markedly, and for a K_t of 21.0 the notch strength at -423° F is less that that at 75° F. The various data indicate that, at the cryogenic temperatures, a change in the value of K_t from 3.0 to 21.0 can reduce the notch strength by as much as a factor of 2. At 75° F the effect of K_t is not as great because the alloy is generally notch insensitive at this temperature (fig. 3(a)). Reductions in notch strength at 75° F of about 16 percent are shown, however, when K_t is increased from 3.0 to 21.0.

E-1447

Variables Influencing Mechanical Properties

The reason for the large variations of the sharp-notch tensile strength for a given value of K_t, such as those shown in figure 5(c), is not clearly understood. Factors other than K_t are obviously affecting the notch strength. According to references 1 and 2, a principal variable affecting the mechanical properties of the Ti-6Al-4V alloy in a given heat and heat-treated condition is the interstitial content. Increased interstitial levels generally increase smooth tensile strength and may, in turn, cause notch sensitivity. Although the interstitial gas content hydrogen, nitrogen, and oxygen can be of importance, it is not believed to be a factor in the data shown in figure 5 for a K_t of 21.0. Table I shows that the interstitial gas content of heats M-7197, M-7373, and M-8702 was essentially the same. An examination of the microstructure of these three heats also showed no significant differences. In heat M-8702, however, the carbon content was higher than in either heat M-7197 or M-7373, and heat M-8702 had the highest smooth tensile strength and also the lowest notch strength.

The elongation behavior (fig. 5(d)) for all data sources is similar with one exception. The elongation for heat M-7373 is not significantly lower at -423° F than at the higher temperatures.

SUMMARY OF RESULTS

The results of the present experimental investigation of the mechanical properties of two heats of Ti-6Al-4V sheet material at 75°, -320°, and -423° F can be summarized as follows:

1. The smooth tensile and yield properties of the alloy approximately doubled as the temperature was lowered from 75° to -423° F.

2. Solution treatment of the alloy increased the tensile strength slightly relative to that of the material in the annealed condition; the yield stress was essentially the same for both heat treatments.

3. The notch sensitivity of the annealed material varied considerably at -320° F depending on the heat and the resulting strength level, heat M-7197 being essentially notch insensitive and heat M-7373 being notch sensitive with a ratio of notch to smooth tensile strength of 0.76. At -423° F, both heats indicated that the alloy was quite notch sensitive, the ratio of notch to smooth tensile strength ranging from 0.41 to 0.59. Solution treatment of the material increased its notch sensitivity relative to that for the annealed condition.

4. The notch strength ratio varied inversely with smooth tensile strength for the three test temperatures.

5. Both annealed and solution-treated material as-welded was essentially 100 percent weld efficient from 75° to -423° F. The notch strength of weld metal of both annealed and solution-treated materials was generally lower than that of the parent metal. (Weld- to parent-metal-strength ratio ranged from about 1.0 to 0.64).

Consideration of the data of other investigators in conjunction with the data obtained herein results in the following comparisons:

1. The spread in smooth tensile and yield data for the various heats was essentially the same at room temperature and at the cryogenic temperatures.

2. The notch tensile strengths from several investigators differed considerably throughout the temperature range considered; for the most part the differences were due to variations in notch acuity (i.e., stress-concentration factor), material (heat), interstitial content, and specimen thickness. There was some indication that a high carbon content increased tensile strength but lowered notch strength.

E-1447

Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio, February 12, 1962

REFERENCES

1. Holden, F. C., Schwartzberg, F. R., and Ogden, H. R.: Tensile Properties of Titanium Alloys at Low Temperatures. Rep. 107, Defense Metals Info. Center, Jan. 15, 1959.

2. Christian, J. L.: Mechanical Properties of Titanium and Titanium Alloys at Cryogenic Temperatures. Rep. MRG-189, Convair-Astronautics, Oct. 1960.

3. McGee, Robert L., Campbell, James E., Carlson, Robert L., and Manning, George K.: The Mechanical Properties of Certain Aircraft Structural Metals at Very Low Temperatures. TR 58-386, WADC, Nov. 1958.

4. Espey, G. B., Jones, M. H., and Brown, W. F., Jr.: Sharp-Edge-Notch Tensile Characteristics of Several High-Strength Titanium Sheet Alloys at Room and Cryogenic Temperatures. Spec. Tech. Pub. 287, ASTM, 1960.

5. Espey, G. B., Jones, M. H., and Brown, W. F., Jr.: A Preliminary Report on Sharp Notch and Smooth Tensile Characteristics for a Number of Ultra High Strength Sheet Alloys. Proc. ASTM, vol. 59, 1959, pp. 837-871; discussion, pp. 872-884.

6. Hanson, Morgan P.: Smooth and Sharp-Notch Tensile Properties of Cold-Reduced AISI 301 and 304L Stainless-Steel Sheet at 75°, -320°, and -423° F. NASA TN D-592, 1961.

7. Peterson, R. E.: Stress Concentration Design Factors, Appendix A. John Wiley & Sons, Inc., 1953, pp. 136-138.

E-1447

TABLE I. - THERMAL TREATMENT AND CHEMICAL COMPOSITION OF Ti-6Al-4V SHEET

Heat	Thermal treatment	Nominal thickness, in.	Composition, percent							Data source
			Al	V	Fe	C	H_2	N_2	O_2	
M-7197	Annealed at 1350° F for 8 hr	0.035	6.0	4.0	0.10	0.015	0.0085	0.015	0.122	Present investigation
M-7197	Solution-treated at 1670° F for 1 hr	.035	6.0	4.0	.10	.015	.0084	.015	.118	
M-7373	Annealed at 1350° F for 8 hr	.030	6.2	4.0	.08	.015	.0054	.013	.125	
M-8702	Annealed	.063	6.0	4.2	.09	.028	.004	.010	.116	NASA (ref. 4)
M-8619	Annealed	.090	5.8	4.1	.09	.028	.005	.008	(a)	Convair (ref. 2)
M-8907	Annealed	.063	6.1	3.9	.09	.028	.0049	.022	.110	
B-23132	Annealed	.063	(a)	(a)	(a)	(a)	(a)	(a)	(a)	
M-23262	Annealed	.063	6.21	3.81	.16	.007	.0118	.010	(a)	
(a)	Annealed	.064	6.27	4.21	.20	.04	.0134	.011	(a)	Battelle (ref. 3)

[a]Not available.

E-1447

TABLE II. - MECHANICAL PROPERTIES OF Ti-6Al-4V SHEET FROM TWO HEATS

Direction	75° F				-320° F				-423° F			
	Yield strength, ksi (a)	Smooth tensile strength, ksi	Elongation, percent (b)	Notch tensile strength, ksi	Yield strength, ksi (a)	Smooth tensile strength, ksi	Elongation, percent (b)	Notch tensile strength, ksi	Yield strength, ksi (a)	Smooth tensile strength, ksi	Elongation, percent (b)	Notch tensile strength, ksi
Heat M-7197, annealed, 0.035-in. sheet												
Longitudinal	123 120	129 124	15.0 13.5	151 147	178 175 187	207 203 205	6.0 11.0 11.7	183 193 197	237 239 239 242	241 241 242 245	2.5 5.0 2.0 3.5	146 132 138
	122	127	14.3	149	180	205	9.6	191	239	242	3.3	139
Transverse	116 120	118 122	13.5 13.5	146 147	193 196	200 201	10.0 7.5	215 193 203	238 234 241 ---	243 236 245 239	5.0 2.0 6.5 3.5	141 148
	118	120	13.5	147	195	201	8.8	204	238	241	4.3	145
Heat M-7373, annealed, 0.030-in. sheet												
Longitudinal	128 127	142 143	11.5 11.0	143	--- 218 215	221 225 223	5.0 10.5 11.0	166 160	256 255 257	270 268 263	8.5 ---- 10.0	108 112
	128	143	11.3	143	217	223	8.8	163	256	267	9.3	110
Weld properties; heat M-7373, annealed, 0.030-in. sheet												
Longitudinal	127 127	146 143	9.0 9.0	129 130	207 209	223 224	7.0 11.3	100 107 c100	256 252 255 250	267 262 270 265	2.5 1.0 3.5 2.0	104 89 115
	127	145	9.0	130	208	224	9.2	104	253	266	2.3	103
Heat M-7197, solution treated, 0.035-in. sheet												
Longitudinal	124 124	145 144	13.0 10.5	161 159	--- 182 208 193	225 218 226 225	17.0 14.0 17.0 14.5	139 141	224 --- 237	257 244 265	8.5 3.0 4.5	136 111 126
	124	145	11.8	160	194	224	15.6	140	231	255	5.3	124
Transverse	124 126	144 145	9.5 12.0	161 154	203 198	220 223	13.0 15.0	145 158	225 211 217	257 248 252	4.5 6.0 5.5	125 115 128
	125	145	10.8	158	201	222	14.0	152	218	252	5.3	123
Weld properties; heat M-7197, solution treated, 0.035-in. sheet												
Longitudinal	120 ---	143 141	11.0 11.0	127 129	194 187	221 220	11.0 7.5	139 150	227 219	255 251	4.0 4.0	109 98 122 113
	120	142	11.0	128	190	221	9.3	145	223	253	4.0	111
Transverse	122 ---	141 138	12.0 10.5	123 122	187 191	220 221	13.0 9.0	126 127	239 235 217	252 265 254	3.0 6.0 4.0	118 106 112
	122	140	11.3	123	190	221	11.0	127	230	257	4.3	112

[a]0.2 percent offset.
[b]2-in. gage length.
[c]Stress relieved at 1300° F for 1 hr.

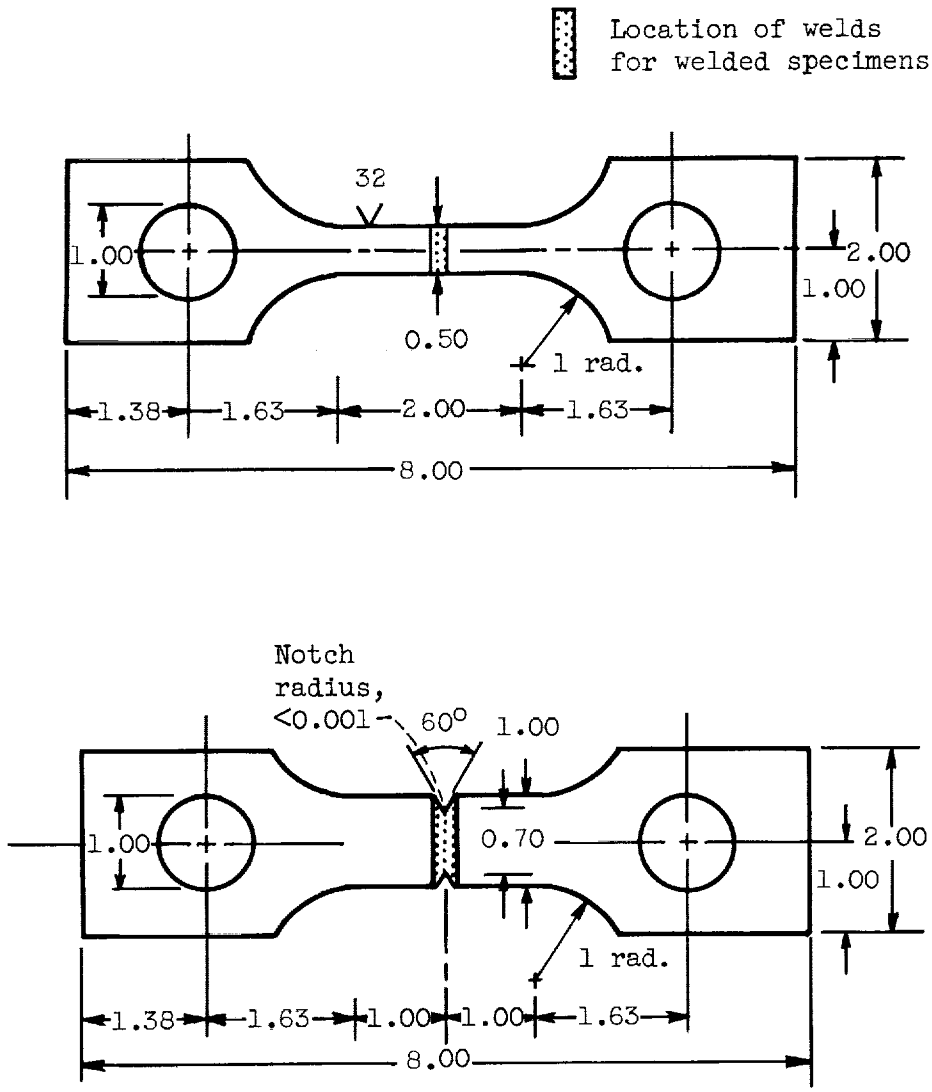
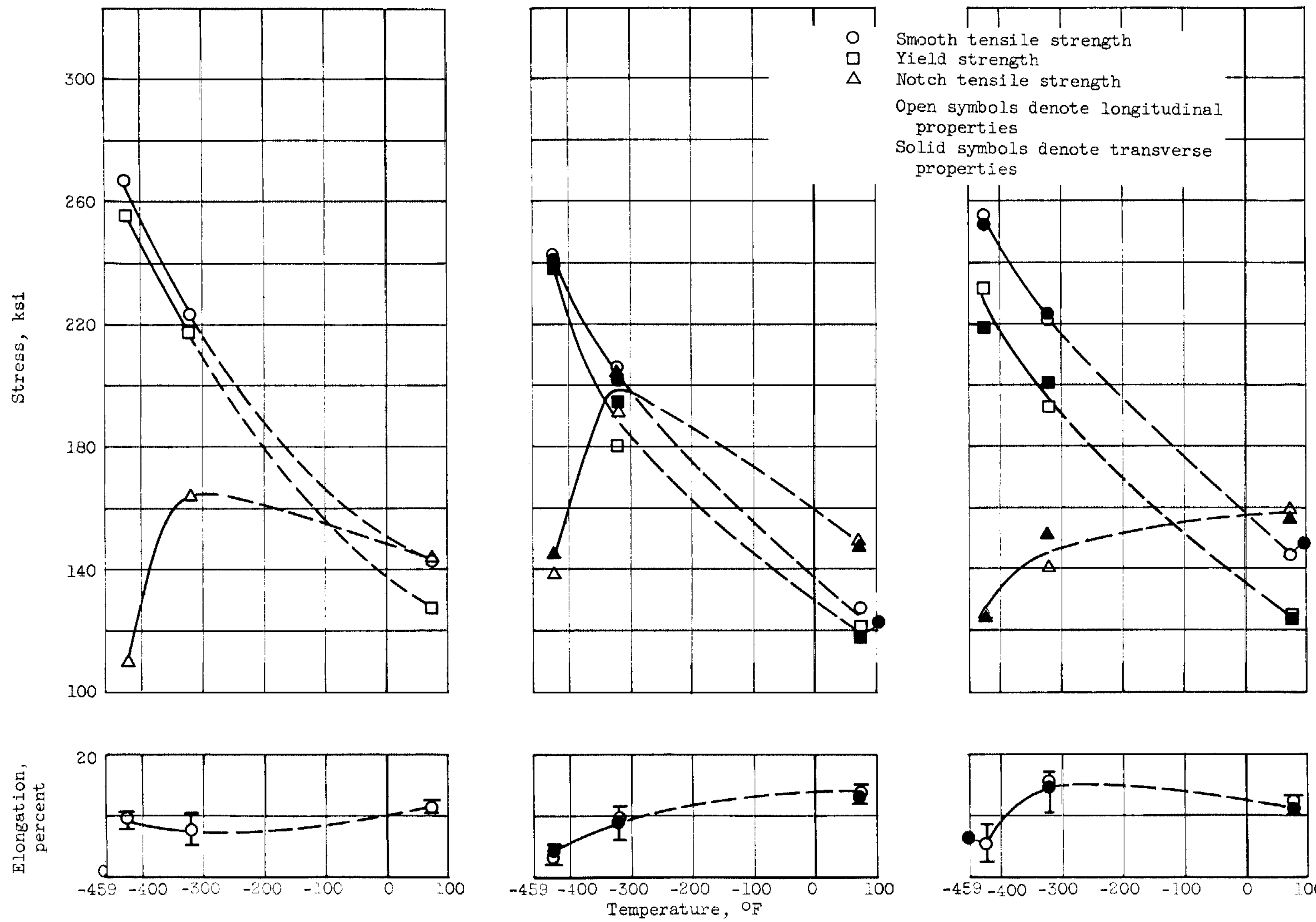


Figure 1. - Smooth and sharp-notch sheet tensile specimens. (Dimensions in inches.)

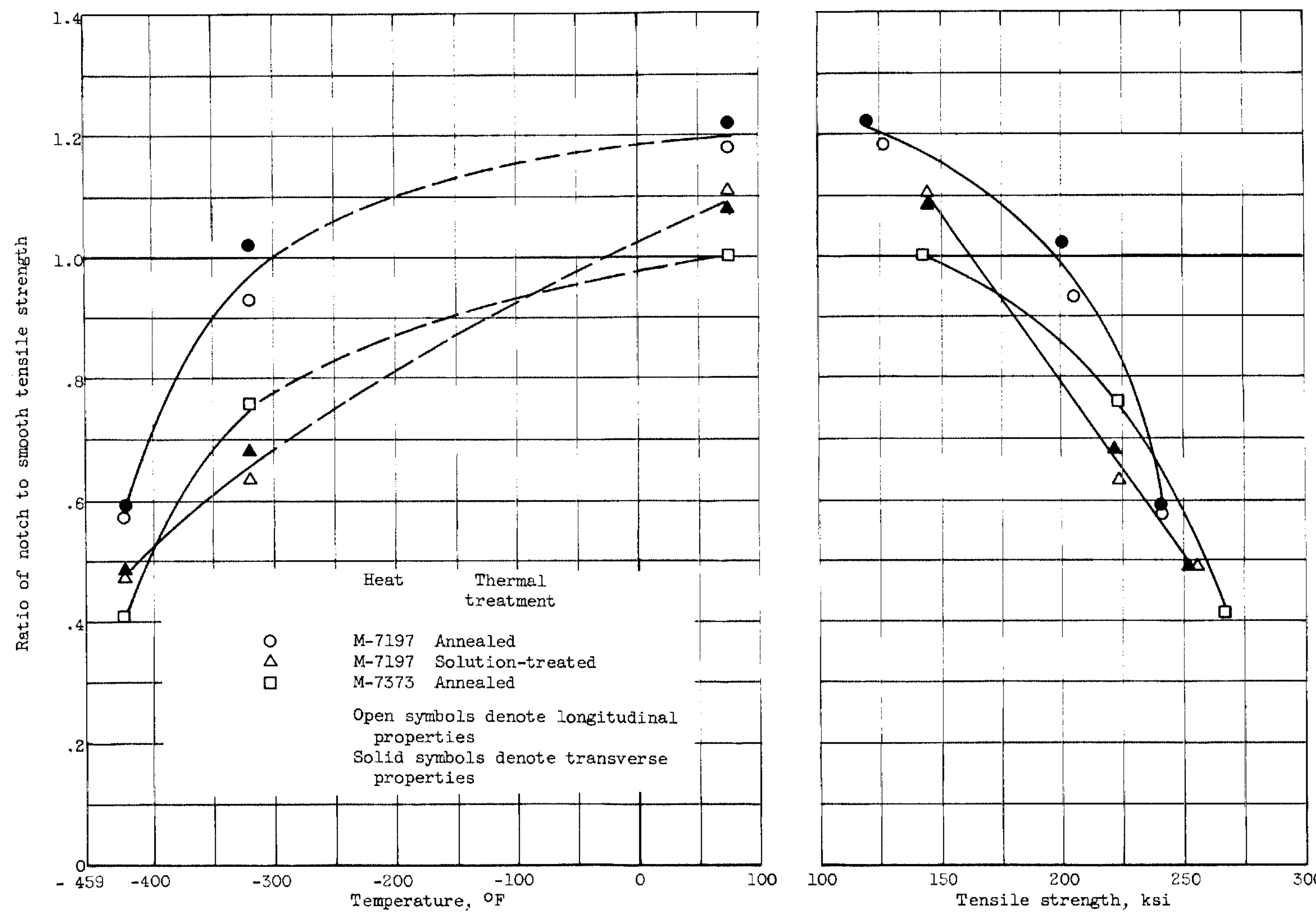


(a) Annealed, heat M-7373.

(b) Annealed, heat M-7197.

(c) Solution-treated, heat M-7197.

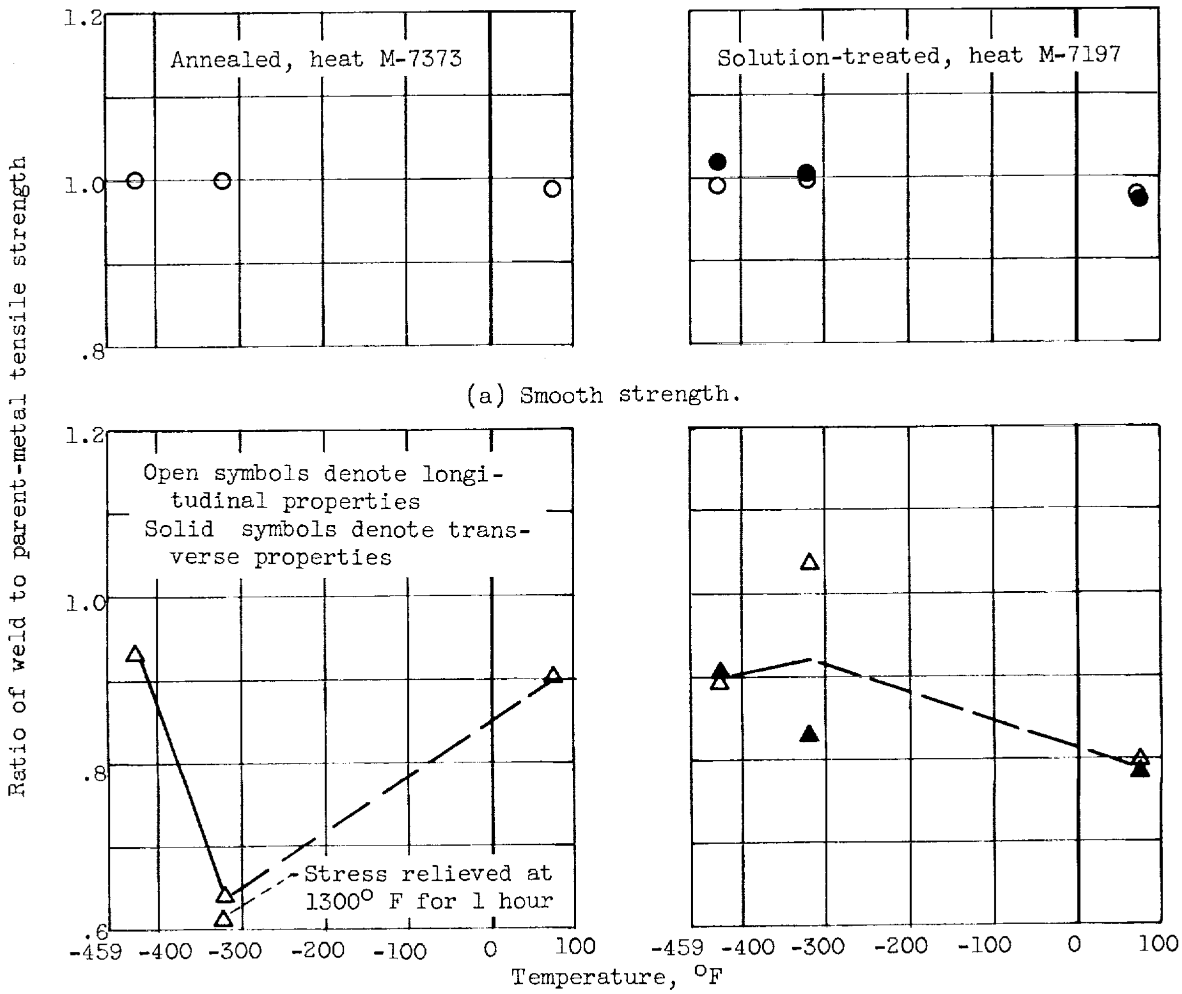
Figure 2. - Strength and elongation of Ti-6Al-4V sheet with various thermal treatments as functions of temperature.



(a) Temperature.

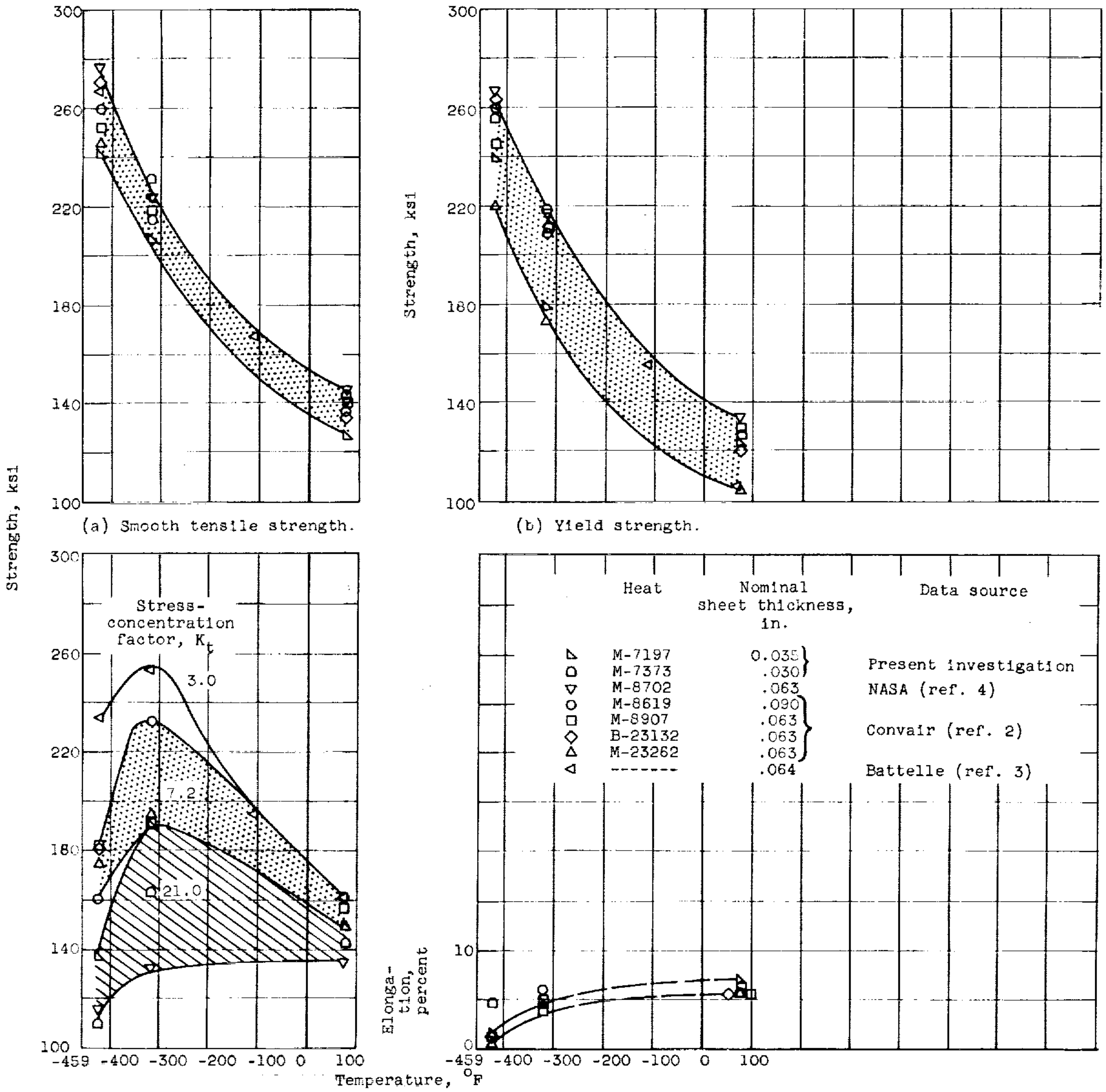
(b) Tensile strength.

Figure 3. - Strength ratio for Ti-6Al-4V sheet with various thermal treatments as a function of temperature and ultimate tensile strength.



(b) Notch strength.

Figure 4. - Weld to parent-metal strength ratio for Ti-6Al-4V sheet with various thermal treatments as function of temperature.



(c) Notch tensile strength.

(d) Percent elongation.

Figure 5. - Longitudinal strength and elongation of annealed Ti-6Al-4V sheet as functions of temperature.

NASA TN D-1282
National Aeronautics and Space Administration.
SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES.
Morgan P. Hanson and Hadley T. Richards. May 1962. 18p. OTS price, $0.50.
(NASA TECHNICAL NOTE D-1282)

Smooth tensile and yield strengths, notch tensile strength, and elongation are reported for annealed materials tested uniaxially. Test results are reported from various sources for material from eight different heats. Notch data are presented for stress-concentration factors of 3.0, 7.2, and 21.0. Some data are presented for the material in the solution-treated condition. Smooth and sharp-notch tensile data are given for annealed and solution-treated material in the as-welded condition.

Copies obtainable from NASA, Washington

I. Hanson, Morgan P.
II. Richards, Hadley T.
III. NASA TN D-1282

(Initial NASA distribution:
25, Materials, engineering;
51, Stresses and loads;
52, Structures.)

NASA

NASA TN D-1282
National Aeronautics and Space Administration.
SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES.
Morgan P. Hanson and Hadley T. Richards. May 1962. 18p. OTS price, $0.50.
(NASA TECHNICAL NOTE D-1282)

Smooth tensile and yield strengths, notch tensile strength, and elongation are reported for annealed materials tested uniaxially. Test results are reported from various sources for material from eight different heats. Notch data are presented for stress-concentration factors of 3.0, 7.2, and 21.0. Some data are presented for the material in the solution-treated condition. Smooth and sharp-notch tensile data are given for annealed and solution-treated material in the as-welded condition.

Copies obtainable from NASA, Washington

I. Hanson, Morgan P.
II. Richards, Hadley T.
III. NASA TN D-1282

(Initial NASA distribution:
25, Materials, engineering;
51, Stresses and loads;
52, Structures.)

NASA

NASA TN D-1282
National Aeronautics and Space Administration.
SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES.
Morgan P. Hanson and Hadley T. Richards. May 1962. 18p. OTS price, $0.50.
(NASA TECHNICAL NOTE D-1282)

Smooth tensile and yield strengths, notch tensile strength, and elongation are reported for annealed materials tested uniaxially. Test results are reported from various sources for material from eight different heats. Notch data are presented for stress-concentration factors of 3.0, 7.2, and 21.0. Some data are presented for the material in the solution-treated condition. Smooth and sharp-notch tensile data are given for annealed and solution-treated material in the as-welded condition.

Copies obtainable from NASA, Washington

I. Hanson, Morgan P.
II. Richards, Hadley T.
III. NASA TN D-1282

(Initial NASA distribution:
25, Materials, engineering;
51, Stresses and loads;
52, Structures.)

NASA

NASA TN D-1282
National Aeronautics and Space Administration.
SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES.
Morgan P. Hanson and Hadley T. Richards. May 1962. 18p. OTS price, $0.50.
(NASA TECHNICAL NOTE D-1282)

Smooth tensile and yield strengths, notch tensile strength, and elongation are reported for annealed materials tested uniaxially. Test results are reported from various sources for material from eight different heats. Notch data are presented for stress-concentration factors of 3.0, 7.2, and 21.0. Some data are presented for the material in the solution-treated condition. Smooth and sharp-notch tensile data are given for annealed and solution-treated material in the as-welded condition.

Copies obtainable from NASA, Washington

I. Hanson, Morgan P.
II. Richards, Hadley T.
III. NASA TN D-1282

(Initial NASA distribution:
25, Materials, engineering;
51, Stresses and loads;
52, Structures.)

NASA

NASA TN D-1282
National Aeronautics and Space Administration.
SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES. Morgan P. Hanson and Hadley T. Richards. May 1962. 18p. OTS price, $0.50.
(NASA TECHNICAL NOTE D-1282)

Smooth tensile and yield strengths, notch tensile strength, and elongation are reported for annealed materials tested uniaxially. Test results are reported from various sources for material from eight different heats. Notch data are presented for stress-concentration factors of 3.0, 7.2, and 21.0. Some data are presented for the material in the solution-treated condition. Smooth and sharp-notch tensile data are given for annealed and solution-treated material in the as-welded condition.

Copies obtainable from NASA, Washington

I. Hanson, Morgan P.
II. Richards, Hadley T.
III. NASA TN D-1282

(Initial NASA distribution: 25, Materials, engineering; 51, Stresses and loads; 52, Structures.)

NASA

NASA TN D-1282
National Aeronautics and Space Administration.
SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES. Morgan P. Hanson and Hadley T. Richards. May 1962. 18p. OTS price, $0.50.
(NASA TECHNICAL NOTE D-1282)

Smooth tensile and yield strengths, notch tensile strength, and elongation are reported for annealed materials tested uniaxially. Test results are reported from various sources for material from eight different heats. Notch data are presented for stress-concentration factors of 3.0, 7.2, and 21.0. Some data are presented for the material in the solution-treated condition. Smooth and sharp-notch tensile data are given for annealed and solution-treated material in the as-welded condition.

Copies obtainable from NASA, Washington

I. Hanson, Morgan P.
II. Richards, Hadley T.
III. NASA TN D-1282

(Initial NASA distribution: 25, Materials, engineering; 51, Stresses and loads; 52, Structures.)

NASA

NASA TN D-1282
National Aeronautics and Space Administration.
SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES. Morgan P. Hanson and Hadley T. Richards. May 1962. 18p. OTS price, $0.50.
(NASA TECHNICAL NOTE D-1282)

Smooth tensile and yield strengths, notch tensile strength, and elongation are reported for annealed materials tested uniaxially. Test results are reported from various sources for material from eight different heats. Notch data are presented for stress-concentration factors of 3.0, 7.2, and 21.0. Some data are presented for the material in the solution-treated condition. Smooth and sharp-notch tensile data are given for annealed and solution-treated material in the as-welded condition.

Copies obtainable from NASA, Washington

I. Hanson, Morgan P.
II. Richards, Hadley T.
III. NASA TN D-1282

(Initial NASA distribution: 25, Materials, engineering; 51, Stresses and loads; 52, Structures.)

NASA

NASA TN D-1282
National Aeronautics and Space Administration.
SMOOTH AND SHARP-NOTCH PROPERTY VARIATIONS FOR SEVERAL HEATS OF Ti-6Al-4V SHEET AT ROOM AND CRYOGENIC TEMPERATURES. Morgan P. Hanson and Hadley T. Richards. May 1962. 18p. OTS price, $0.50.
(NASA TECHNICAL NOTE D-1282)

Smooth tensile and yield strengths, notch tensile strength, and elongation are reported for annealed materials tested uniaxially. Test results are reported from various sources for material from eight different heats. Notch data are presented for stress-concentration factors of 3.0, 7.2, and 21.0. Some data are presented for the material in the solution-treated condition. Smooth and sharp-notch tensile data are given for annealed and solution-treated material in the as-welded condition.

Copies obtainable from NASA, Washington

I. Hanson, Morgan P.
II. Richards, Hadley T.
III. NASA TN D-1282

(Initial NASA distribution: 25, Materials, engineering; 51, Stresses and loads; 52, Structures.)

NASA